Modeling of Design Structural Loads for a 40-kW Furling Wind Turbine

Craig Hansen and Dean Davis, Windward Engineering

With the support of

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and

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Objectives

- ***Estimate design loads for the prototype of a 40 kW Bergey system***
  - ***Furling model in question***
  - ***Hence the present objective...***
- ***Determine sensitivity of furling behavior to aerodynamic model and turbine geometry***

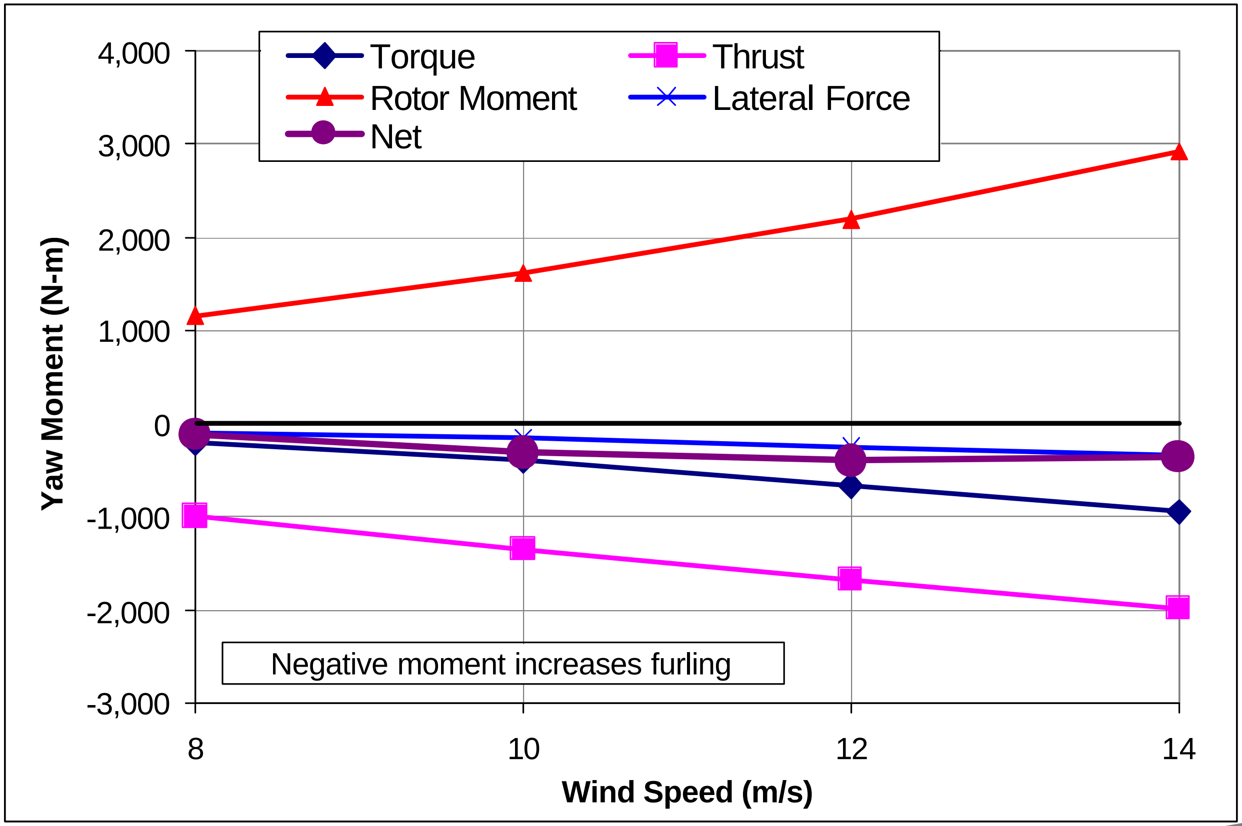
ADAMS Model of a Bergey 40 kW System

- **Structure**
  - **Flexible blades (60 dof each)**
  - **Thrust offset easily adjusted**
  - **Free-yaw, free-furling (with stops)**
  - **Linear furl damper (single-acting, unfurling motion only)**
  - **Rigid tower**
  - **Rigid drive train with generator torque/speed curve**
  - **Properties do not match current design of Bergey system**
- **Aerodynamics**
  - **AeroDyn aerodynamics model (version 11.25)**
    - Optional use of dynamic stall, dynamic inflow, and UIUC post-stall corrections
  - **Aerodynamic forces on tail via C_L and C_D lookup table**
    - No adjustment for rotor wake in this version

Rotor Contributions to the Furling Moment

Steady wind (0.2 power law), 90 rpm, -20° yaw error

(Dynamic stall, Pitt & Peters dynamic inflow, no post-stall correction)



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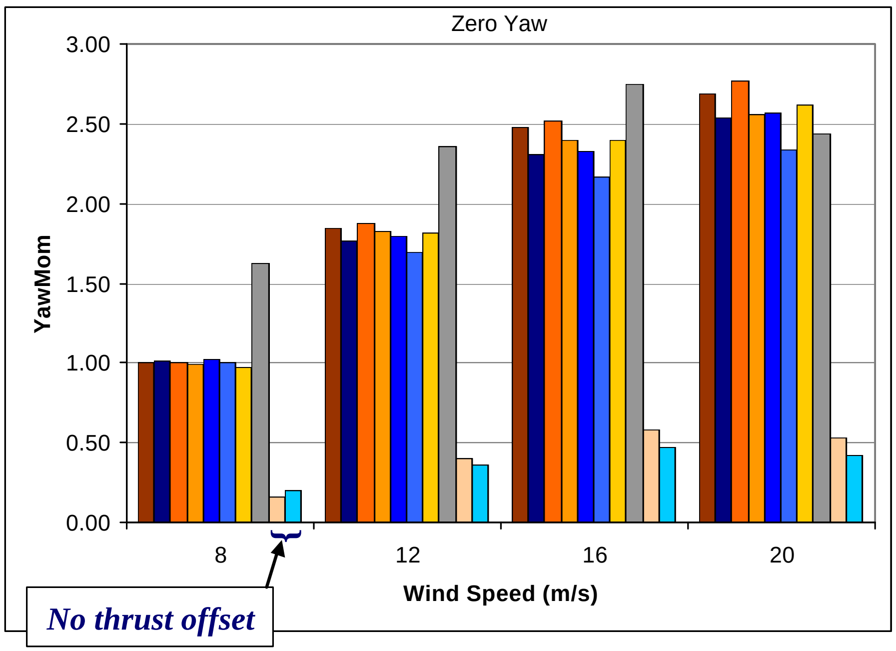
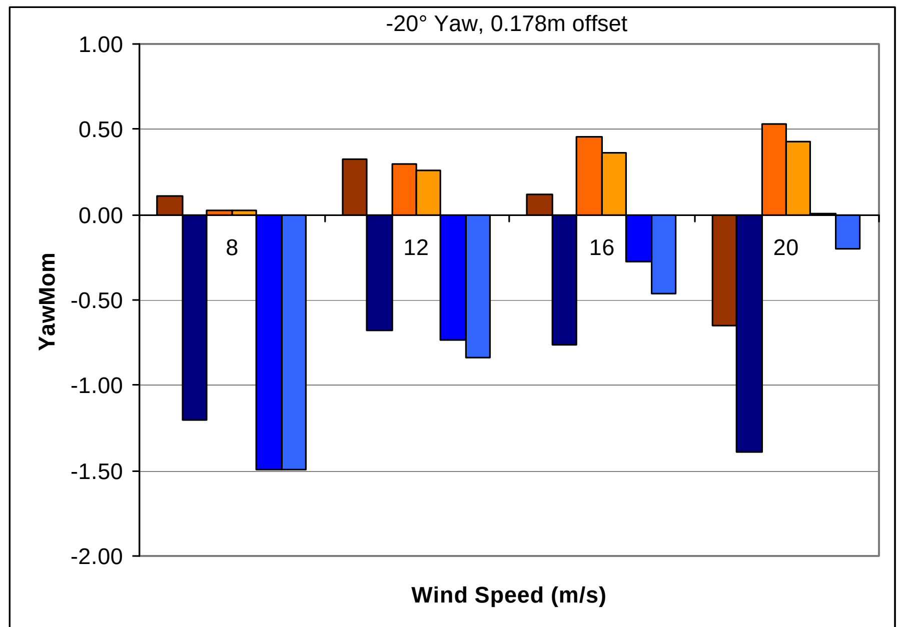
Sensitivity of Yaw Moment to Aerodynamic Model

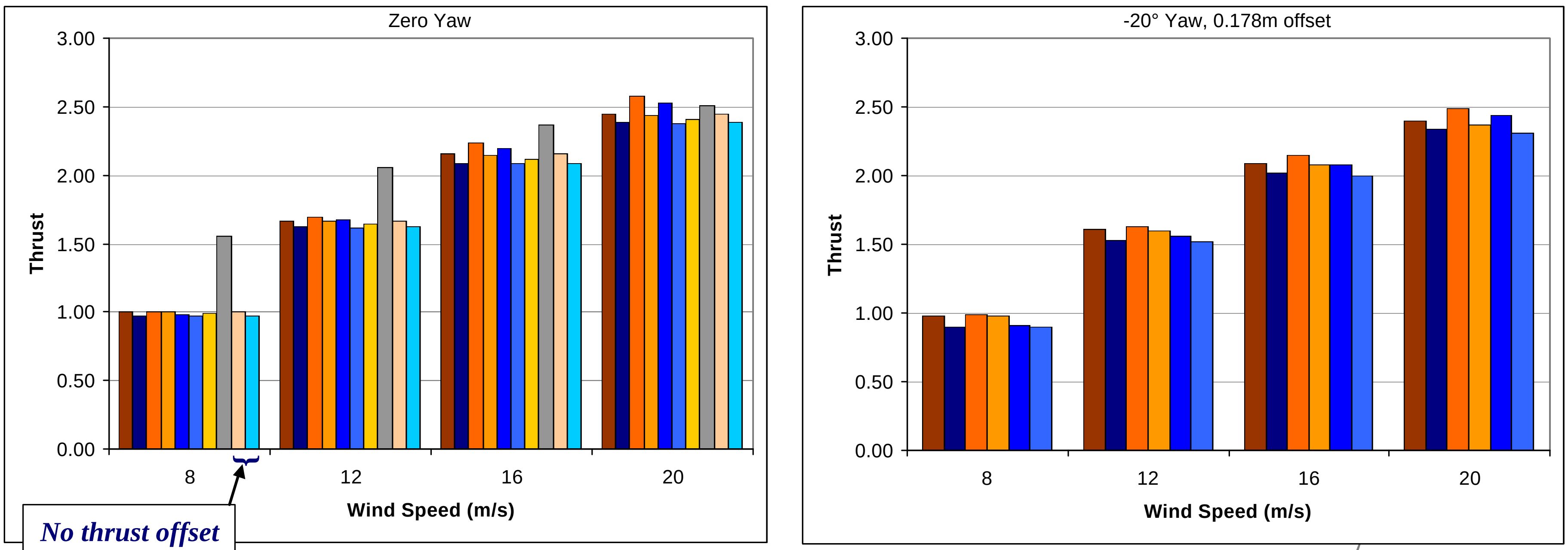
- Steady wind (0.2 power law), 90 rpm, no tail force, fixed yaw and zero furl angle
- Normalized by 8 m/s case at zero yaw, with dynamic stall and dynamic inflow
- Color key: Blues ⇨ No dynamic inflow; Golds ⇨ With dynamic inflow; Gray ⇨ No wake. Last two series with zero yaw have zero thrust offset. Dynamic stall and post-stall options also exercised





Sensitivity of Rotor Thrust to Aerodynamic Model

- *Steady wind (0.2 power law), 90 rpm, no tail force, fixed yaw and zero furl angle*
- *Normalized by 8 m/s case at zero yaw, with dynamic stall and dynamic inflow*
- *Color key: Blues ⇨ No dynamic inflow; Golds ⇨ With dynamic inflow; Gray ⇨ No wake. Last two series with zero yaw have zero thrust offset. Dynamic stall and post-stall options also exercised*



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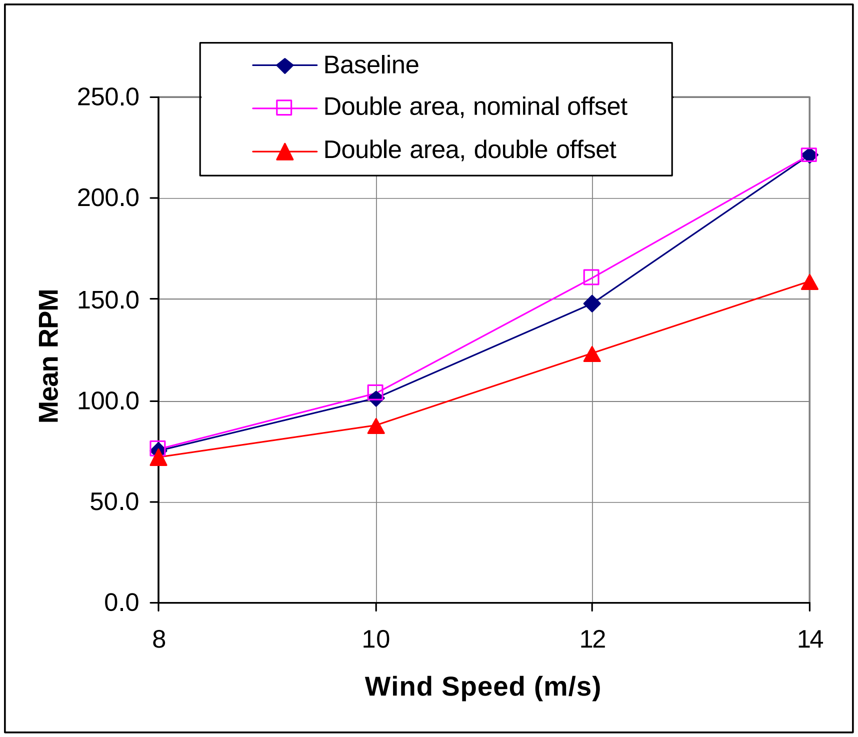
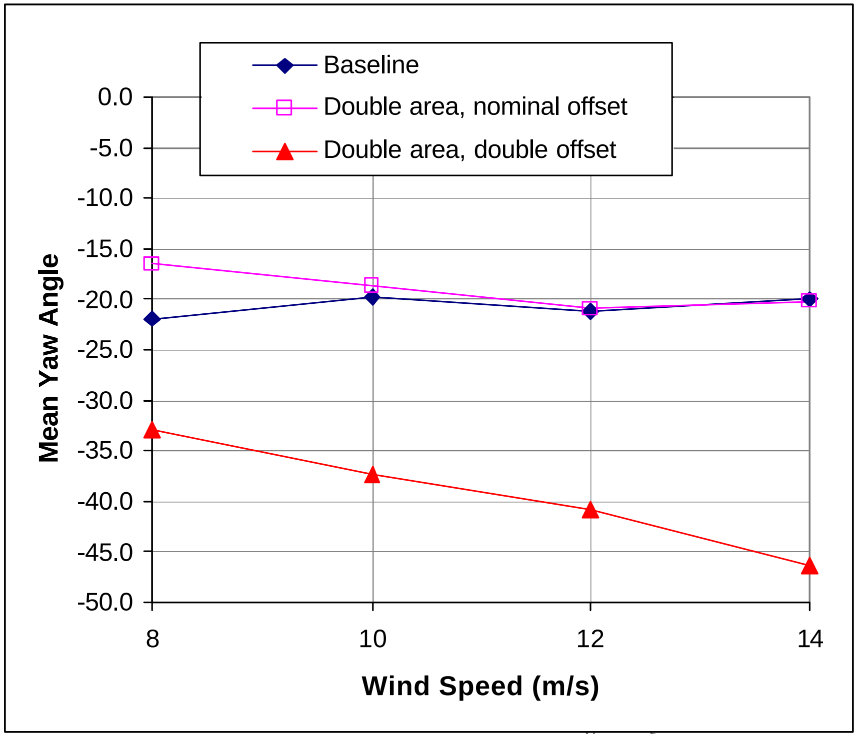
Predicted Furling Behavior

- Effect of doubling the tail area and the thrust offset
- IEC turbulence (2x10 minutes) with free yaw, free-furl, variable speed alternator, dynamic stall, dynamic inflow, and furling damper





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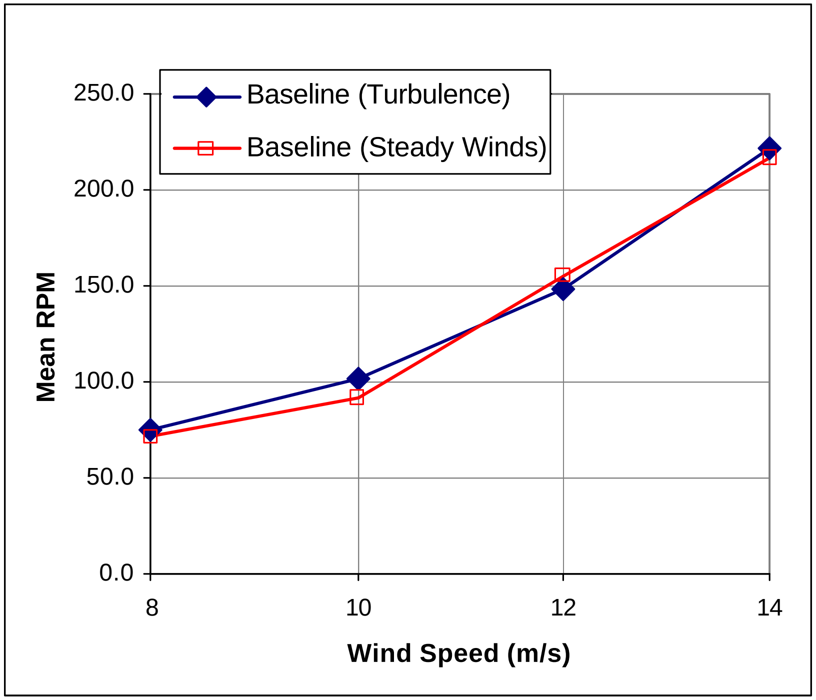
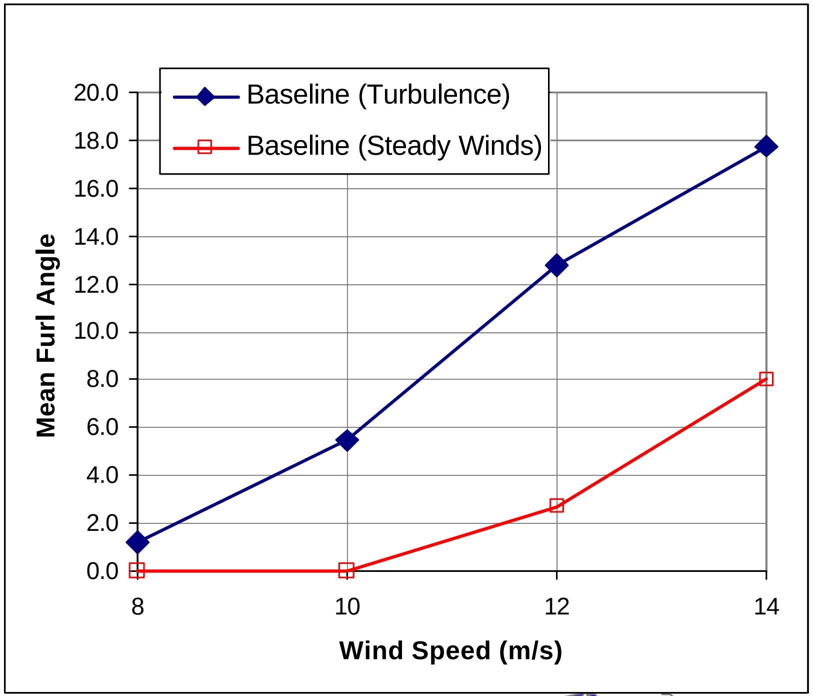
Turbulence Affects Mean Behavior

- ***Predictions in turbulent (IEC) and steady winds, both with 0.2 power law mean shear***
- ***Free yaw, free-furl, variable speed alternator, dynamic stall, dynamic inflow, and single-acting furling damper***





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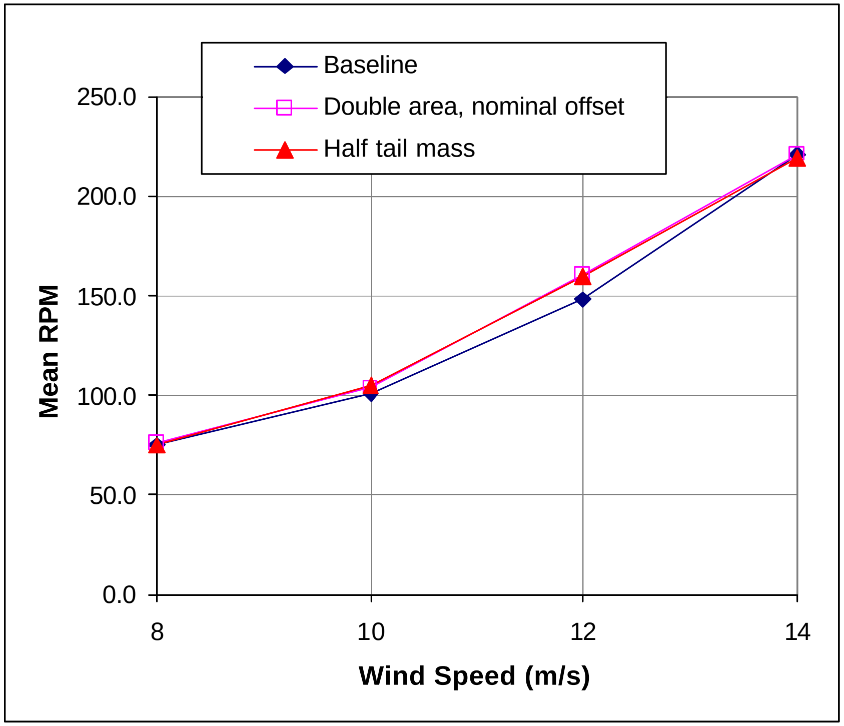
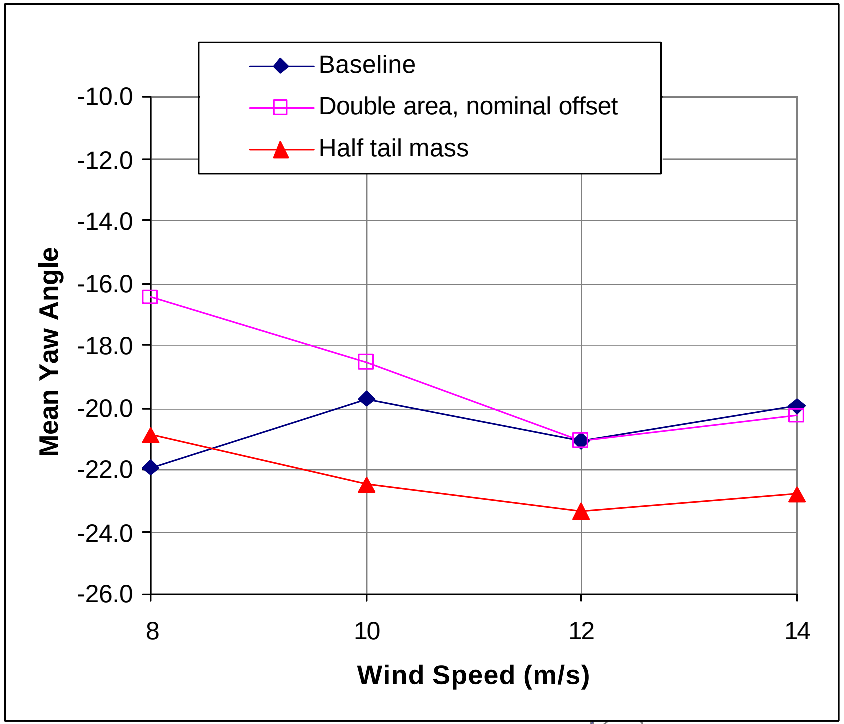
Sensitivity to Tail Vane Size and Weight

- *Effect of doubling the tail area and reducing the tail mass by one-half*
- *IEC turbulence (2x10 minutes) with free yaw, free-furl, variable speed alternator, dynamic stall, dynamic inflow, and furling damper*

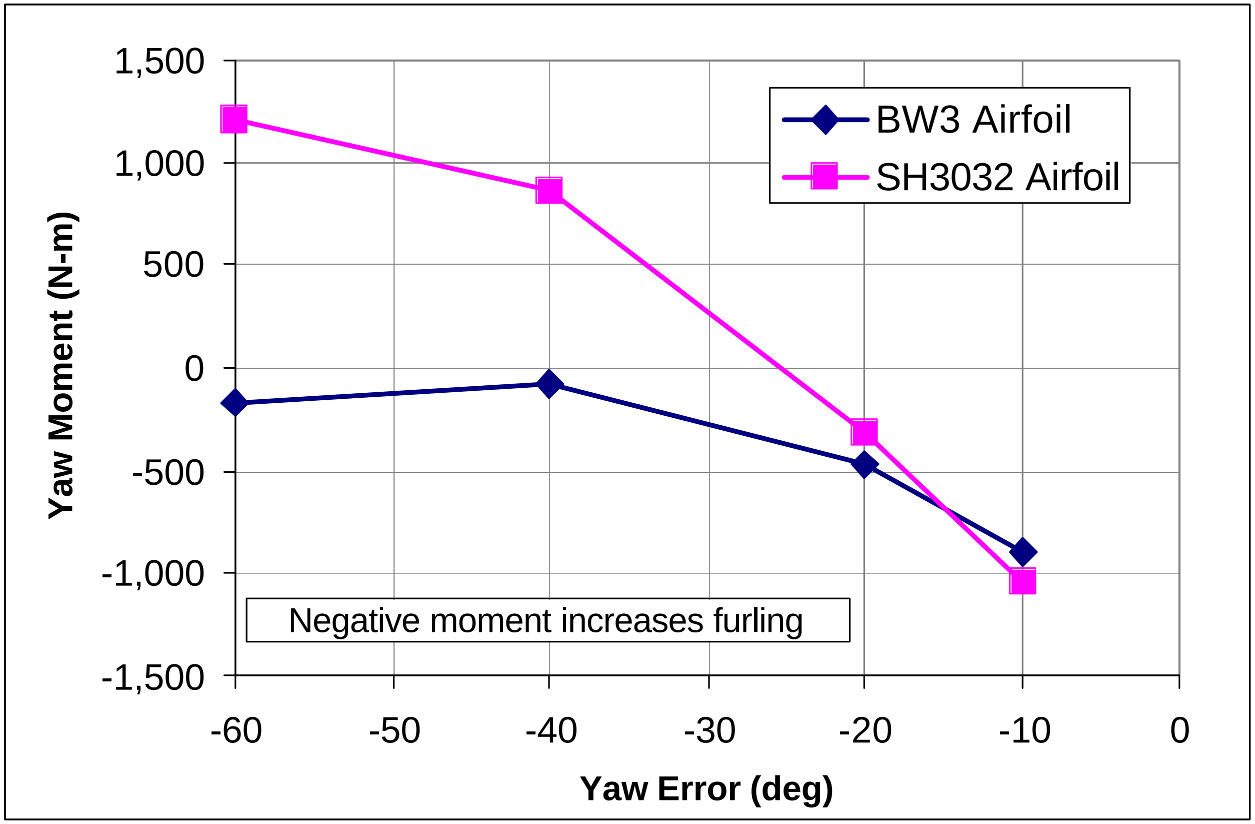




Sensitivity to Airfoil Characteristics

Steady 10 m/s wind (0.2 power law), 90 rpm, fixed yaw and furl, no tail force

Dynamic stall, Pitt & Peters dynamic inflow, no post-stall correction



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Sensitivity to Forward Offset

- *Yesterday we ran simulations using "ramp" winds and three values of forward offset (upwind distance from yaw axis to hub center)*
  - *Used 9.4%, 13%, and 16% of rotor diameter*
  - *Winds from 10 to 16 m/s in 1 m/s increments*
  - *0.1905 m lateral offset and 2° tilt (different from previous work)*
- *Saw virtually no effect on RPM, power, or loads. See minor effect on furl and yaw angles*
- *This result is contrary to intuition and Bergey test experience. We need to confirm the result with model checks*

Conclusions

- ***Furling is a result of small differences in large contributors to the net yaw moment***
- ***Furling response is most sensitive to the thrust offset***
  - ***Tail area and mass are less important***
  - ***Airfoil selection and rotor speed can be important***
- ***Dynamic inflow theory has a strong influence on predicted yaw moment when there is a small yaw error***
- ***These factors make furling one of the most difficult situations to model***
- ***These conclusions apply only to the rotor we modeled. The Bergey 40 kW system and other systems may differ markedly***

Future Plans

- Model validation using Bergey 40-kW test results
- Model validation using Ames wind-tunnel test results for the UAE rotor (NREL support)
- Model validation using Whisper 900 test results from our Small Turbine Field Verification project (DOE support)